In this issue

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Front Cover

Schematic diagram of the current Regional Meteorological Data Communication Network (RMDCN).

Editorial

The ability to give accurate warning of severe weather events would provide a major contribution towards avoiding the consequent injuries and deaths, environmental damage, social disruption and economic losses. The article on page 2 by Roberto Buizza and Tony Hollingsworth describes the application of the Ensemble Prediction System (EPS) to the prediction of three major storms that caused considerable damage in Europe during 1999. The results of the study indicate that the EPS could be used effectively to warn of such events, and the authors suggest that it is time to promote the use of ensemble products as input to risk assessment models.

The Regional Meteorological Data Communication Network (RMDCN) is an important new initiative to meet the ECMWF and WMO Region VI requirements within a single managed data network. The RMDCN steering group recommended that ECMWF should undertake the task of leading and coordinating the procurement, implementation and operational monitoring of the network for all RA VI members. Details of the steps taken to establish the RMDCN and of the configuration that has been brought into operational use are described in the article on page 12 by Matteo Dell'Acqua and Tony Bakker. ❑

Changes to the Operational Forecasting System

On 12 September 2000, the data assimilation procedure moved from 6-hour to 12-hour cycling. 4D-Var now processes the observations in 12-hour sets, spanning 03 – 15 UTC for the 12 UTC analysis, and 15 – 03 UTC for the 00 UTC analysis. Surface analyses still run every six hours. Analysis fields are still archived every six hours. Other changes included in this model version are:

- use of more accurate background trajectory in 4D-Var, thanks to an improved interpolation procedure, the use of the prognostic cloud scheme and first-guess cloud fields;
- change to the 4D-Var incremental formulation by which the low-resolution increment is added to the high-resolution trajectory at analysis time (00 UTC and 12 UTC), instead of at the start of the 4D-Var window;
- new quality-control step that prevents the use of observations that the incremental formulation of 4D-Var cannot handle correctly;
- resetting of the stratospheric ozone and switching off of the multivariate coupling between ozone and vorticity;
- monitoring of TOVS radiances in cloudy areas.

On 21 November, the model resolution was upgraded from T_L319 to T_L511 resolution in the deterministic mode, and from T_L159 to T_L255 in the ensemble mode (EPS). This is roughly a reduction in grid size from 60 to 40km (deterministic) and from 120 to 80km (EPS). Vertical resolution remains unchanged in all model configurations. Other changes included in this model version are:

- the data assimilation now runs its minimisation (inner loop) at T_L159 (was T63 previously) using new semi-Lagrangian tangent linear and adjoint codes.
- the wave model in the T_L511 deterministic model continues to run at approximately 55 km horizontal resolution with an increase in spectral information from 12 to 24 directions and from 25 to 30 frequencies. The wave model in the EPS will run in shallow-water mode with an increased horizontal resolution of approximately 110 km with 12 directions and 25 frequencies (no change). The European-waters model continues to run at approximately 28 km with an increase in spectral information from 25 to 30 frequencies, while the number of direction remains at 24.

The T511 and T255 pre-operational suites have demonstrated their positive impact during the testing period on the mean scores for upper-level fields and precipitation, both in deterministic and probabilistic mode. Meteorological evaluation on individual cases has also shown an overall improvement. ❑

François Lalaurette

Severe Weather Prediction using the ECMWF EPS:

– The European Storms of December 1999 –

Human activities have become increasingly more vulnerable to severe weather (*Kunkel et al. 1999, Easterling et al. 1999*) and there is an increasing demand that numerical weather prediction centres provide reliable forecasts of such severe events. Early indications of severe weather events are necessary to improve the quality of systems designed to issue early warnings of potentially severe damages. Severe events are often associated with very energetic phenomena such as flooding, strong winds and extreme temperatures. In forecasting such events, small errors in the initial conditions may grow very quickly and affect the forecast accuracy. Furthermore, model uncertainties due to the discrete representation of the system equations may increase the forecast error growth. As a consequence, forecasting systems based on single deterministic forecasts may not be reliable.

The Ensemble Prediction System (EPS) operational at the European Centre for Medium-Range Weather Forecasts (ECMWF) (*Molteni et al. 1996*) is designed to simulate both initial and model uncertainties. The initial uncertainties are simulated by starting the multiple integrations from perturbed initial conditions. Model uncertainties due to the parametrized physical processes are simulated by stochastically perturbing the model equations (*Buizza et al. 1999*).

The performance of the ECMWF forecasting system (operational deterministic $T_L319L60$ model and the EPS) in predicting three severe storms that caused great damage in Europe in December 1999 in assessed. The first storm hit Denmark and Germany on 3 and 4 December, and the other two storms crossed France and Germany on 26 and 28 December. Strong winds associated with intense fast-moving cyclones caused serious disruptions, several deaths and billion of dollars of damages (*Bell et al. 2000*). Numerous buildings and vast areas of forests were destroyed by the winds, while transport and power outages affected large areas for several days. The impact of an increase of the ensemble system horizontal resolution is also investigated. A higher-resolution experimental ensemble system is also compared with the EPS.

For reasons of space, this work presents few verifications based on mean-sea-level pressure predictions. The reader is referred to *Buizza & Hollingsworth (2000)* for a more comprehensive and detailed report.

At the time of the storms (December 1999) the ECMWF EPS was based on 51 members at $T_L159L40$ resolution (spectral triangular truncation T159 with linear grid, *Buizza et al. 1998*). The EPS included a scheme to simulate also model uncertainties due to random model error in the parametrized physical processes (Buizza et al. 1999). For each day d, the 50 perturbed initial conditions were defined by adding initial perturbations to the operational ($T_L319L60$) analysis, interpolated to the EPS resolution ($T_L159L40$). The initial perturbations were defined using the singular vectors growing in the forecast range between day d and day d+2 at initial time, and the singular vectors that had grown in the past between day d-2 and day d at final time. The initial perturbations were scaled to be locally comparable to analysis error estimates (*Molteni et al. 1996*).

The EPS performance is compared with the performance of a high-resolution ensemble system (HEPS) which includes 51 members as the EPS but it uses a higher horizontal resolution (T_L255 instead of T_L159). The HEPS unperturbed initial conditions (the ones used to start the control forecasts) are defined from a higher-resolution ($T_L511L60$) analysis. Hereafter, the term 'resolution increase' will mean 'EPS horizontal resolution-increase from $T_L159L40$ to $T_L255L40$ and analysis resolution increase from $T_L319L60$ to $T_L511L60$'.

Forecast verification is focused on mean-sea-level pressure (MSLP). The quality of single deterministic forecasts is assessed (i) by computing the root-mean-square error (RMSE) inside the verification area and (ii) by computing the errors in the prediction of the intensity (Intensity Error, IE) and of the position (Position Error, PE) of the MSLP minimum value. The IE (in hPa) is the absolute difference between the forecast and analysis pressure minimum and the PE is the distance (in km) between the forecast and the analysed position. The quality of the probabilistic prediction of MSLP events is assessed by computing the Brier score (BS) (*Brier 1950*).

The Danish (and German) storm affected Denmark, Germany and other Baltic countries on 3 and 4 December 1999. A low-pressure system located northwest of Ireland at 00 UTC on 3 December deepened from 996hPa to 961hPa during the following 12 hours while moving eastward. In the next 12 hours the cyclone continued eastward into the Baltic Sea while

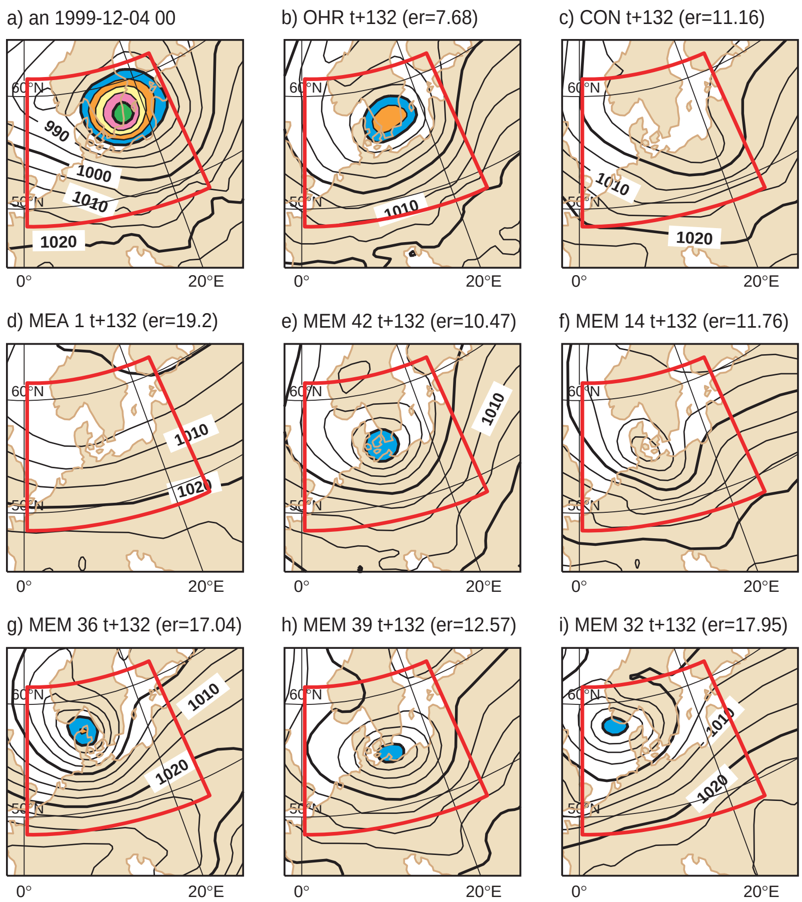

Figure 1 The Danish storm. (a) The MSLP analysis at the verification time 00 UTC 4 December 1999. The other panels show t+132h forecasts started at 12 UTC 28 November (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) The T_L319L60 forecast (IE=13hPa, PE=149km), (c) the EPS control forecast (IE=33hPa, PE=348km), (d) the EPS ensemble-mean forecast, (e) EPS member 42 (the lowest RMSE, IE=18hPa (the second lowest), PE= 341km), (f) EPS member 14 (the second lowest RMSE, IE=25hPa, PE=452km), (g) EPS member 36 (IE=17hPa (the lowest), PE=637km), (h) EPS member 39 (IE=21hPa, PE=333km), and (i) EPS member 32 (IE=20hPa, PE=637km). No EPS member had an RMSE smaller than the T_L319L60 forecast and one member had an RMSE smaller than the EPS control. The contour interval is 5hPa, with shading for values below 980hPa.

MSLP dropped from 961hPa to 957hPa. During the following 12 hours the cyclone continued to move eastward while weakening its intensity.

Forecasts are verified at 00 UTC on 4 December when the cyclone reached its strongest intensity and was located north-east of Denmark. The verification area used to compute the RMSEs and the BSs has longitude between 0 and 25°E and latitude between 48°N and 62°N (see frames in Figure 1). Consideration of other verification times would have led to qualitatively similar conclusions.

Figures 1(a) and (b) show the analysis at 00 UTC 4 December and the operational T_L319L60 forecast started on 28 November (t+132h). The operational T_L319L60 model predicted the storm with a good accuracy, with a 13hPa IE and a 150km PE. Figure 2 (with a similar layout) shows the operational t+84h T_L319L60 forecast issued on 30 November (t+84h). In contrast to the operational T_L319L60 forecast issued two days earlier, this operational T_L319L60 forecast was rather poor, with a 28hPa IE and a 292km PE.

Table 1(a) summarises the intensity and position errors of the operational T_L319L60 forecasts. The operational T_L319L60 forecasts issued between 26 November (t+180h) and 30 November (t+84h) were very inconsistent, with forecasts with low RMSEs and IE/PEs, such as the ones issued on 28 November (Figure 1) alternating with forecasts with large errors. In terms of the IE and PE, only the operational T_L319L60 forecasts issued on 1 (t+60h) and 2 (t+36h) December were very accurate, with the IE and PE smaller than 10hPa and 300km, respectively.

In terms of RMSE, the EPS control and the operational T_L319L60 forecasts performed similarly for forecast ranges longer than 60 hours while the operational T_L319L60 forecast performed better for shorter forecast times (not shown). The ensemble mean, which is the most immediate product that can be constructed using the EPS, had an RMSE higher than the EPS control forecast for all forecast ranges. In terms of intensity errors (Table 1(a)), the operational T_L319L60 forecasts were always more accurate than the EPS control forecast, apart for the forecast started on 26 November (t+156h, not shown). In contrast, the EPS control forecasts issued on 29 November (t+108h, not shown), 30 November (t+84h, Figure 2) and 1 December (t+60h) had smaller errors than the operational T_L319L60 forecasts, in terms of PEs (Table 1(a)).

Considering now all the ensemble members, the EPS started on 26 November (t+180h, not shown) gave some indications of the possibility of a storm affecting the verification area. At this forecast range, one EPS member predicted the storm with an IE smaller than 10hPa and a PE between 300km and 600km, and three EPS members had an IE and PE smaller than 20hPa and 600km, respectively (for this forecast time, the operational T_L319L60 had a 25hPa IE and a 133 km PE). The EPS forecast issued the next day (27 November, t+156h, not shown) provided similar indications, while the operational T_L319L60 forecast failed to predict a storm inside the verification region (see the large IEs and PEs reported in Table 1(a)).

Figure 1 shows the forecasts started on 28 November (t+132h) given by the EPS control, the ensemble-mean and selected EPS members (these members are selected so that the two EPS members with the smallest RMSE inside the verification region and the two members with the smallest intensity error are shown). None of the EPS members had an RMSE lower than the operational T_L319L60 forecast inside the verification region. EPS member 42 had the lowest RMSE of the EPS forecasts and the second lowest IE, while EPS member 36 had the lowest IE. EPS members 14, and 39, ranked in second and fourth positions in terms of RMSE, had IEs between 20 and 30hPa and PEs between 300 and 600km.

a) Danish Storm (verifying at 00 UTC 4 December 1999)

Initial date	Forecast time (h)	Intensity error (hPa)		Position error (km)	
		T_L319L60	EPS control	T_L319L60	EPS control
26 Nov	T+180h	24.7	15.8	133	348
27 Nov	T+156h	70.3	30.1	1169	739
28 Nov	T+132h	13.1	33.1	149	249
29 Nov	T+108h	36.1	35.6	394	140
30 Nov	T+84h	28.4	26.7	292	107
1 Dec	T+60h	4.6	9.3	141	111
2 Dec	T+36h	1.3	4.0	81	251

b) First French Storm (verifying at 12 UTC 26 December 1999)

Initial date	Forecast time (h)	Intensity error (hPa)		Position error (km)	
		T_L319L60	EPS control	T_L319L60	EPS control
19 Dec	T+168h	25.9	35.3	825	231
20 Dec	T+144h	43.7	–	636	–
21 Dec	T+120h	–	–	–	–
22 Dec	T+96h	19.1	5.1	225	507
23 Dec	T+72h	1.3	2.0	366	81
24 Dec	T+48h	13.5	11.1	406	77
25 Dec	T+24h	2.4	3.6	175	128

c) Second French Storm (verifying at 00 UTC 28 December 1999)

Initial date	Forecast time (h)	Intensity error (hPa)		Position error (km)	
		T_L319L60	EPS control	T_L319L60	EPS control
20 Dec	T+180h	28.3	25.0	1151	751
21 Dec	T+156h	4.3	33.0	169	654
22 Dec	T+132h	14.7	11.8	666	833
23 Dec	T+108h	15.1	18.5	472	134
24 Dec	T+84h	32.2	29.5	471	795
25 Dec	T+60h	22.7	23.0	904	596
26 Dec	T+36h	22.8	23.3	526	623

Table 1 Intensity and position errors of the operational T_L319L60 and the EPS T_L159L40 control forecasts for (a) the Danish storm verified at 00 UTC 4 December 1999, (b) the first French storm verified at 12 UTC 26 December 1999 and (c) the second French storm verified at 00 UTC 28 December 1999.

This contrast between the RMSE and the IEs and PEs highlights the fact that these scores measure different aspects of the forecast error; if used in conjunction they give a more complete picture of the accuracy of a forecasting system.

Table 2(a) summarises the IEs and PEs of the EPS members for this t+132h forecast range. As mentioned above, the operational T_L319L60 forecast started on this day was very accurate (Table 1(a)). In contrast, the EPS issued on this day failed to produce very accurate forecasts, with only two EPS members (members 42 and 36) characterised by IEs and PEs smaller than 20hPa and 600km, respectively (Table 2(a)). Note that the ensemble-mean forecast (Figure. 1(d)) did not provide any indication of the possibility of a storm affecting the verification area.

Figure 2 shows the ensemble forecasts issued of 30 November (t+84h), and Table 2(b) summarises the IEs and PEs of the EPS members for this forecast range. EPS member 29 had the lowest IE and PE (7hPa and 115km compared with 28hPa and 292km for the operational T_L319L60 forecast, Table 1(a)), and fifteen EPS members had IEs and PEs smaller than 20hPa and 600km, respectively (Table 2(b)). The four best EPS members in terms of RMSE (members 6, 14, 18 and 48) had IEs between 10 and 20hPa and PEs smaller than 300km (Table 2(b)). Note that, as was the case for the EPS started on 28 November, the ensemble-mean forecast (Figure. 2(d)) did not give any indication of the possibility of a storm affecting the verification area.

Figure 3 shows that the number of ensemble members (in all operational (T_L159) ensembles started between 26 November (t+180h) and 2 December (t+36h)) with IEs and PEs smaller than 10hPa and 300km, respectively, was zero for forecast ranges longer than 84 hours. Fewer than three ensemble members had IEs and PEs smaller than 20hPa and 600km, respectively, for forecast ranges longer than 108 hours. At the 84-hour forecast range, more than fifteen EPS members had IEs smaller than 20hPa and PEs smaller than 600km.

Considering the EPS started on 1 December (t+60h), Figure 3 shows that two EPS members had IEs and PEs smaller than 10hPa and 300km (with 5hPa and 131km errors for the best EPS member) and twenty-three members had IEs smaller than 20hPa and PEs smaller than 600km. For this forecast range, the operational T_L319L60 model had an IE and PE of 4.6hPa and 140km, respectively (Table 1(a)). All EPS members started on 2 December (t+36h) had IEs and PEs smaller than 20hPa and 600km, with seven members characterised by errors smaller than 10hPa and 300km.

The ensemble forecasts have been used to predict the probability of occurrence of the event "MSLP lower than 980hPa". The accuracy of the probabilistic forecasts strongly depends on the accuracy of the individual EPS members. The consistent increase of the number of EPS members with small IEs and PEs for shorter lead times is reflected in the gradual improvement in the quality of the probabilistic forecast; this is confirmed by the decrease with forecast time of the BSs computed inside the verification region (not shown). The reader is referred to *Buizza & Hollingsworth 2000* for a more detailed discussion of the skill of probabilistic products.

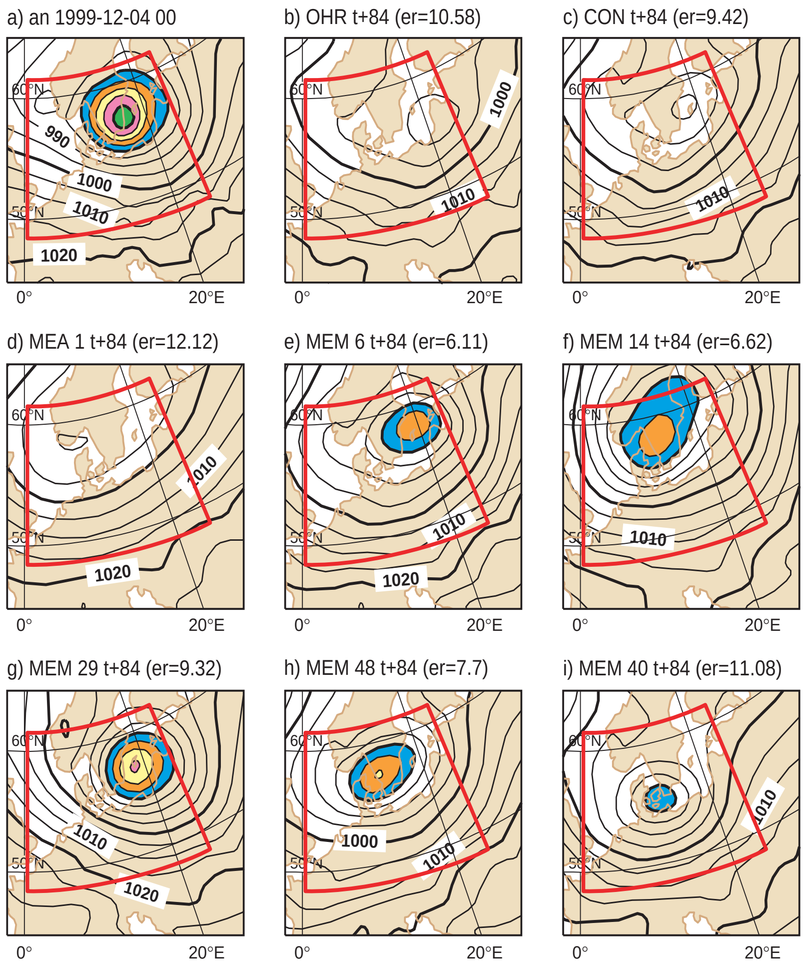

Figure 2 The Danish storm. (a) The MSLP analysis at the verification time 00 UTC 4 December 1999. The other panels show t+84h forecasts started at 12 UTC 30 November (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) The T_L319L60 forecast (IE=28hPa, PE=292km), (c) the EPS control forecast (IE=25hPa, PE=107km), (d) the EPS ensemble-mean forecast, (e) EPS member 6 (the lowest RMSE, IE=14hPa, PE=202km), (f) EPS member 14 (the second lowest RMSE, IE=14hPa, PE=228km), (g) EPS member 29 (IE=7hPa (the lowest), PE=115km), (h) EPS member 48 (IE=13hPa (the second lowest), PE=226km), and (i) EPS member 40 (IE=20hPa, PE=329km). Ten EPS members had RMSEs smaller than the T_L319L60 forecast and seven member had RMSEs smaller than the EPS control. The contour interval is 5hPa, with shading for values below 980hPa.

Figure 4 shows the EPS control, the ensemble mean and some EPS members from the high-resolution HEPS started on 28 November (t+132h) (as before, the HEPS members are selected so that the two EPS members with the smallest RMSE inside the verification region and the two members with the smallest intensity error are shown). The comparison of the HEPS (Figure 4) and the EPS forecasts (Figure 1) shows that the HEPS predicted more correctly both the storm intensity and its position. For this forecast range, HEPS member 2, which has the lowest RMSE of all forecasts (3.06hPa), has an IE of 5hPa and a PE of 120km. HEPS member 3, ranked in second position according to RMSE (7.27hPa), has a 1hPa IE and a 207km PE (for this forecast range, the operational T_L319L60 operational forecast had an RMSE of 7.68hPa and an IE of 13hPa and a PE of 149km). Similar considerations could be drawn by comparing the t+84h EPS forecasts started on 30 November (Figure 2) with the corresponding HEPS forecasts (not shown).

Table 2 summarises (in the bracketed numbers) the impact the horizontal resolution increase on the IEs and PEs of the t+132h and the t+84h forecasts. For both forecast times the HEPS not only has a larger number of good forecasts (Tables 2(a) and (b)) but it also has a lower number of poor forecasts (Tables 1(a) and (b)). This positive impact of resolution is more evident at t+84h. At shorter forecast ranges (t+36h and t+60h, not shown), the HEPS is remarkably more capable than the EPS of predicting the storm intensity and position. The positive impact of the resolution increase is confirmed by the lower BSs obtained for the HEPS probabilistic prediction of the event "MSLP lower than 980hPa" (not shown, see *Buizza & Hollingsworth 2000* for more details).

During the days after Christmas 1999 Western Europe was hit by a sequence of intense storms. The first storm crossed French coast in the early hours of 26 December, causing severe damage. The second storm hit southwestern France on 27 December and the alpine region on 28 December. These two storms originated in the western Atlantic and moved very rapidly eastward in the very strong zonal flow. The two storms were very different in scale; while the first storm was a very small-scale vortex moving extremely rapidly (it crossed France in less than 12 hours), a larger scale characterised the second storm. The atmospheric flow during this period was very complex, with small-scale vortices developing and interacting while moving very rapidly in the strong zonal flow. At one time, three of these intense vortices were positioned very closely, affecting France, the UK and the eastern Atlantic. The fact that the flow was difficult to predict is confirmed by the inconsistent and often-poor operational T_L319L60 forecasts for both storms issued on successive days.

Forecasts for the first storm are verified at 12 UTC 26 December, while forecasts for the second storm are verified at 00 UTC 28 December. Two different verification areas are used to compute the RMSEs and the BSs at the two verification times; each of them centred around the observed position. The first area has longitude between 5°W and 20°E and latitude between 40°N and 57°N, while the second area has longitude between 10°W and 20°E and latitude between 40°N and 57°N. Verification at other times would have drawn qualitatively similar conclusions.

Figures 5(a) and (b) (in a layout similar to Figure 1) shows the analysis at 12 UTC 26 December and the operational T_L319L60 forecast issued on 24 December (t+48h). Table 1(b) indicates the IEs and PEs of the operational T_L319L60 forecast issued over the period 19 December (t+168h) to 25

a) Danish Storm (verifying at 00 UTC 4 December 1999)

28 Nov t+132h	DE 0-300km	DE 300-600km	DE 600-900km	DE > 900km
IE 0-10hPa	0 (2)	0 (3)	0 (2)	0 (2)
IE 10-20hPa	0 (0)	2 (1)	1 (3)	0 (0)
IE 20-30hPa	0 (0)	6 (4)	3 (3)	4 (1)
IE > 30hPa	4 (1)	11 (13)	5 (3)	5 (5)

b) Danish Storm (verifying at 00 UTC 4 December 1999)

30 Nov t+84h	DE 0-300km	DE 300-600km	DE 600-900km	DE > 900km
IE 0-10hPa	1 (0)	2 (4)	1 (6)	0 (0)
IE 10-20hPa	5 (5)	7 (9)	3 (0)	3 (0)
IE 20-30hPa	1 (4)	5 (3)	3 (2)	1 (0)
IE > 30hPa	1 (2)	12 (14)	5 (1)	0 (0)

Table 2 The Danish storm. The number of EPS and HEPS (in brackets) perturbed members with intensity error (IE) and position error (DE) included in defined intervals, for (a) ensembles started on 28 November 1999(t+132h) and (b) on 30 November 1999 (t+84h).

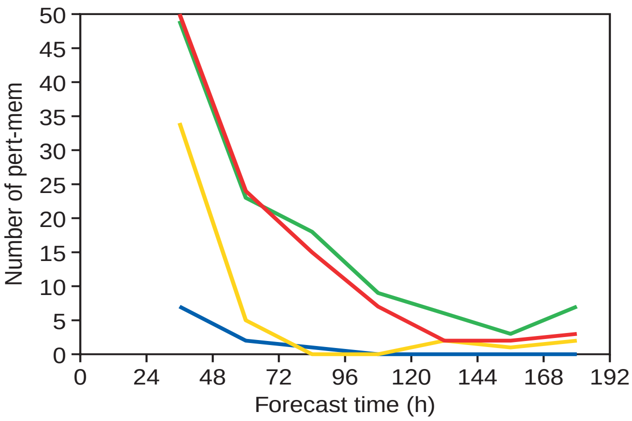

Figure 3 The Danish storm. Results for MSLP forecasts verified at 00 UTC 4 December 1999 showing the numbers of EPS members with intensity and position errors smaller than 10hPa and 300km (blue) and smaller than 20hPa and 600km (red), and the numbers of HEPS (high-resolution EPS) members with intensity and position errors smaller than 10hPa and 300km (yellow) and smaller than 20hPa and 600km (green).

December (t+24h). At the 48-hour forecast range, the operational T_L319L60 forecast almost correctly positioned the large-scale trough (Figure 5) but failed to predict the storm intensity and position (Table 1(b)).

The operational T_L319L60 forecasts issued on 19 December (t+168h, not shown) and on 20 December (t+144h, not shown) were rather accurate in describing the large-scale flow and had RMSEs of about 8hPa but had very large IEs and PEs (Table 1(b)). The operational T_L319L60 forecast issued on 21 December (t+120h, not shown) wrongly predicted a zonal flow instead of the deep trough and had a very large RMSE. The operational T_L319L60 forecast issued the next day (22 December, t+96h, not shown) almost correctly predicted the atmospheric flow and had a small RMSE, but again failed to intensify the cyclone to the observed value (Table 1(b)). Eventually, the operational T_L319L60 forecast started on 23 December (t+72h, not shown) was characterised by very small IEs and PEs (1.3hPa and 366km, Table 1(b)). As already mentioned above, the operational T_L319L60 forecast issued the next day (24 December, t+48h, Figure 5), had a smaller RMSE but failed to predict the storm intensity (13.5hPa IE and 406km PE, Table 1(b)). The operational T_L319L60 forecast issued the following day (25 December, t+24h) almost correctly predicted the storm intensity but misplaced it by 175km (Table 1(b)).

Figures 6(a) and (b) (in a layout similar to Figure 1) show the analysis at 00 UTC 28 December and the operational T_L319L60 forecast issued on 25 December (t+60h). At this forecast range, the operational T_L319L60 forecast missed the prediction of the storm.

Table 1(c) summarises the IEs and PEs of the operational T_L319L60 forecast issued over the period 20 December (t+180h) to 26 December (t+36h). The operational T_L319L60 forecast issued on 20 December (t+180h, not shown) was characterised by an IE of 28hPa and a PE of 1151km (Table 1(c)). The operational T_L319L60 forecast issued the successive day (21 December, t+156h, not shown) was very accurate, both in capturing the large-scale flow and in predicting the storm intensity and location. This forecast had the smallest RMSE and smallest IEs and PEs of all forecasts (4.3hPa and 169km, Table 1(c)). The operational T_L319L60 forecast issued the day after (22 December, t+132h, not shown) was again rather poor, with a 14.7hPa IE and a 666km PE (Table 1(c)). The forecast started on 23 December (t+108h) was the second best of all forecasts (Table 1(c)). The forecasts issued on the following days (24 December, t+84h, not shown, and 25 December, t+60h, Figure 6) were again characterised by large RMSEs and large IEs and PEs (Table 1(c)).

For verification time 12 UTC 26 December, the operational T_L319L60 forecast was better than the EPS control at the 168h and 96h forecast ranges, while the EPS control was better for the other forecast ranges (not shown). In terms of intensity/position errors, (Table 1(b)) shows that the EPS control was worse than the operational T_L319L60 forecast for forecast ranges up to 96h, but it was better for shorter forecast ranges.

Figure 5 shows the EPS control, the ensemble-mean and some members of the forecasts started on 24 December

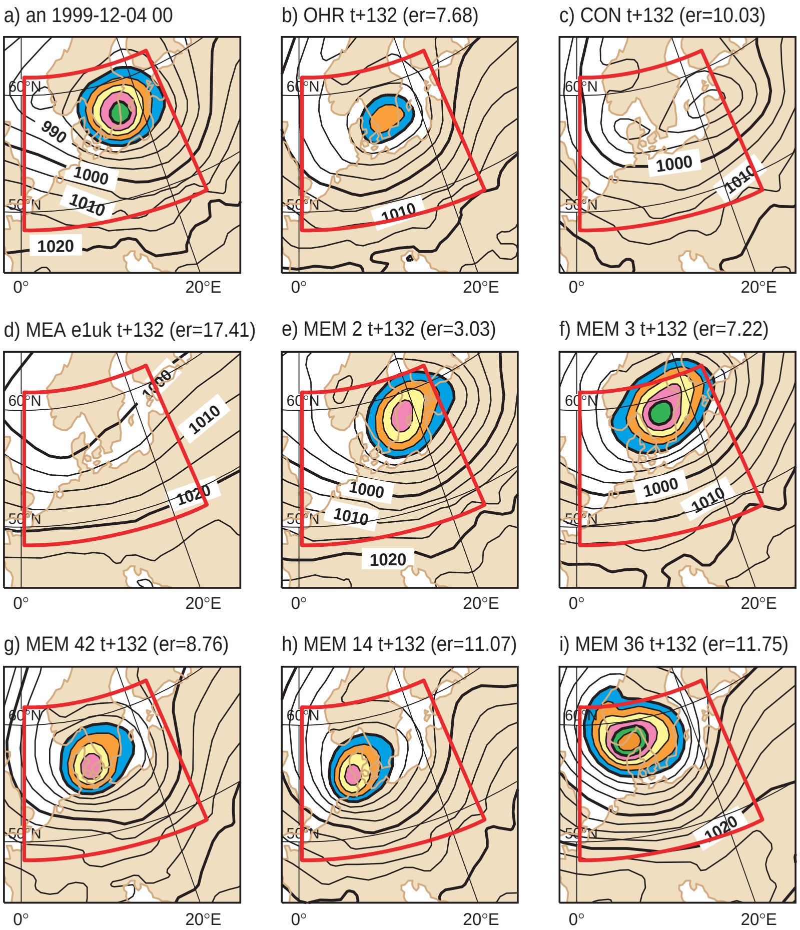

Figure 4 The Danish storm. (a) The MSLP analysis at the verification time 00 UTC 4 December 1999. The other panels show t+132h forecasts started at 12 UTC 28 November (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) The T_L319L60 forecast (IE=13hPa, PE=149km), (c) the high-resolution ensemble (HEPS) control forecast (IE=25hPa, PE=306km), (d) the HEPS ensemble-mean forecast, (e) HEPS member 2 (the lowest RMSE, IE=5hPa, PE=120km), (f) HEPS member 3 (the second lowest RMSE, IE=1hPa (the lowest), PE=207km), (g) HEPS member 42 (IE=4hPa (the second lowest), PE=368km), (h) HEPS member 14 (IE=5hPa, PE=637km), and (i) HEPS member 36 (IE=7hPa, PE=452km). Two HEPS members had RMSEs smaller than the T_L319L60 forecast and three members had RMSEs smaller than the HEPS control. The contour interval is 5hPa, with shading for values below 980hPa.

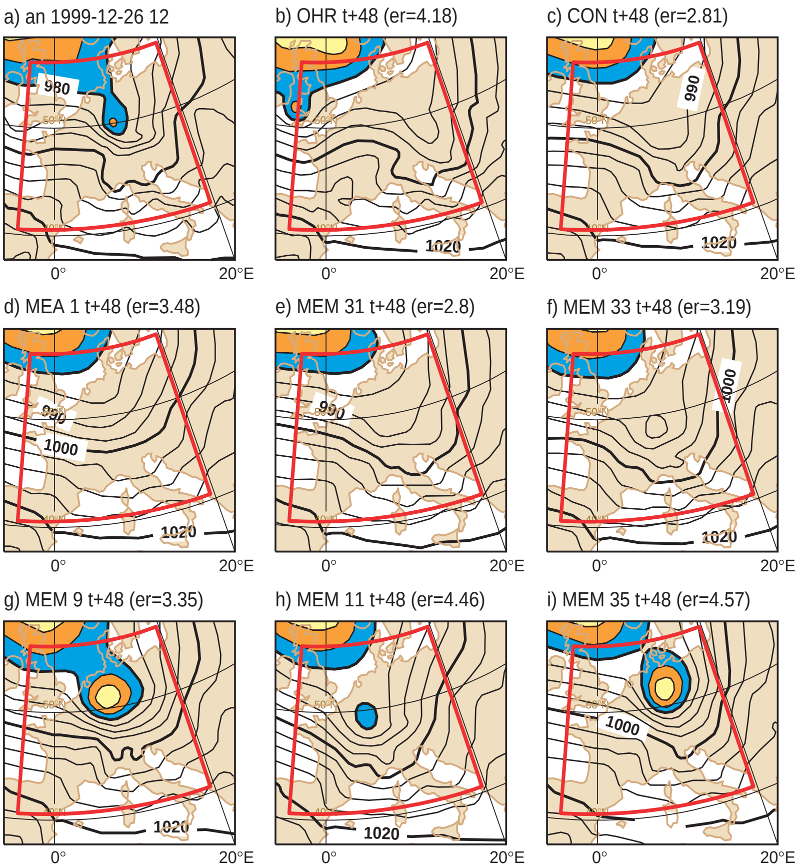

Figure 5 The first French storm. (a) The MSLP analysis at the verification time 12 UTC 26 December 1999. The other panels show t+48h forecasts started at 12 UTC 24 December (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) The T_L319L60 forecast (IE=13hPa, PE=405km), (c) the EPS control forecast (IE=11hPa, PE=76km), (d) the EPS ensemble-mean forecast, (e) EPS member 31 (the lowest RMSE, but no closed minimum), (f) EPS member 33 (the second lowest RMSE, IE=9hPa, PE=207km), (g) EPS member 9 (IE=8hPa (the second lowest), PE=128km), (h) EPS member 11 (IE=4hPa (the lowest), PE=637km), and (i) EPS member 35 (IE=7hPa, PE=200km). Eleven EPS members had RMSEs smaller than the T_L319L60 forecast and one member had an RMSE smaller than the EPS control. The contour interval is 5hPa, with shading for values below 980hPa.

(t+48h). Eleven EPS members had an RMSE smaller than the operational T_L319L60 forecast and six EPS members had IEs smaller than 10hPa and PEs smaller than 600km. EPS member 31 (Figure 5(e)), which had the lowest RMSE, did not predicted any closed cyclonic circulation with a local MSLP minimum value inside the verification region. In contrast, EPS members 33 and 9, ranked in second and fourth position according to RMSE, had IEs of up to 10hPa and PEs between 600 and 900km, with EPS member 9 characterised by the second smallest IE after EPS member 11. Comparison between the RMSEs and the IEs and PEs confirms that these scores measure different aspects of the forecast error and they should be used together to draw a more complete picture of the accuracy of a forecasting system.

Figure 7(a) shows some statistics based on the IEs and PEs of the EPS members for all forecasts issued over the period 19 December (t+168h) to 25 December (t+24h). None of the EPS members predicted the storm with IEs and PEs smaller than 10hPa and 300km, and at most nine members predicted the storm with IEs and PEs smaller than 20hPa and 600km. The EPS gave some indications of the possibility of an intense storm in the forecasts issued on 19 December (t+168h, not shown) and 20 December (t+144h, not shown), with four members characterised by IEs and PEs smaller than 20hPa and 600km. The EPS forecast started on 21 December (t+120h) and 22 December (t+96h) had three members with IEs and PEs smaller than 20hPa and 600km. This number increased in the forecasts issued the next two days to eight and nine members, respectively.

Table 3 summarises the number of EPS forecasts with IEs and PEs within predefined intervals for the forecasts issued on 21 December (t+120h) and on 24 December (t+48h). For the 120h forecast range (Table 3(a)), two EPS members had an IE smaller than 10hPa and a PE between 300 and 600km. At t+72h (Table 3(b)), six EPS members had an IE smaller than 10hPa and a PE between 300 and 600km.

For verification time 00 UTC on 28 December the operational T_L319L60 forecast was better than the EPS control at the 156h and 108h forecast ranges, while the EPS control was better for the other forecast ranges (not shown). In terms of IEs and PEs (Table 1(c)) the operational T_L319L60 forecast and the EPS control had comparable errors for all forecast ranges apart from 156h. For this forecast range the operational T_L319L60 forecast was more accurate and definitely better than the EPS control.

Figure 6 shows the EPS control, the ensemble mean and some EPS members started on 25 December (t+60h). Twenty-eight EPS members had an RMSE smaller than the operational T_L319L60 model. EPS member 1, best in terms of RMSE, had IE = 4hPa and PE = 138km. The two other EPS members with the lowest IEs and PEs, members 31 and 21, are ranked in seventh and ninth position according to RMSE. EPS members 34, ranked in second position according to RMSE, had IE = 17hPa and PE = 183km.

Figure 7(b) shows some statistics based on the IEs and PEs of the EPS members for all forecasts issued over the period 20 December (t+180h) to 26 December (t+36h). For forecast ranges longer than 96h, Figure 7(b) shows that none of the EPS members had IEs and PEs smaller than 10hPa and 300km and that only eight members, at most, had IEs and PEs smaller than 20hPa and 600km. These numbers increase for shorter forecast ranges up to t+60h but they decrease for the t+36h forecast. In fact, the EPS forecasts issued on 26 December (t+36h) had larger IEs and PEs than the forecast issued the day before (Figure 7(b)).

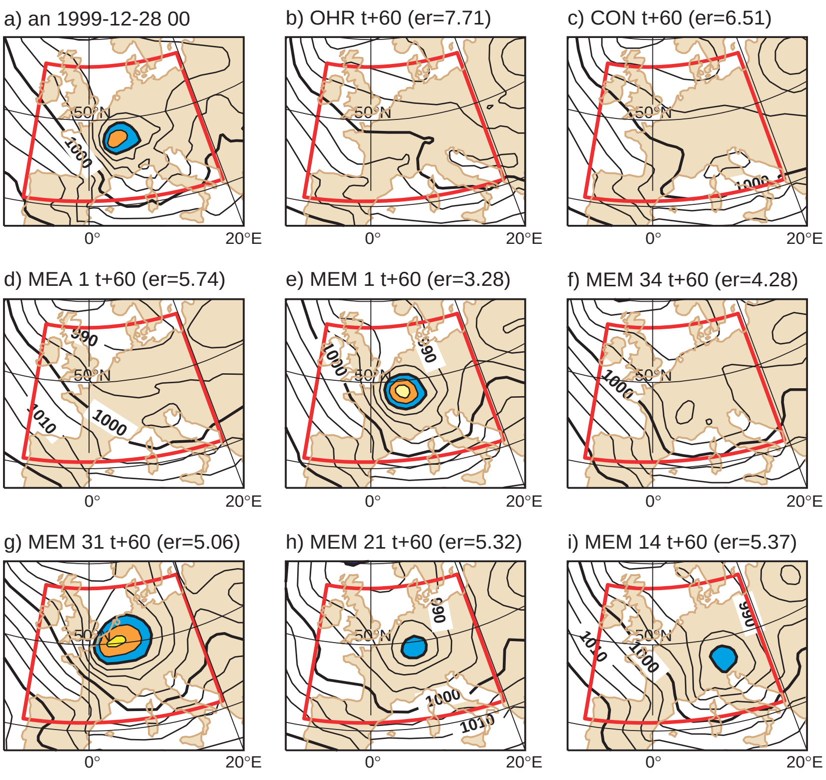

Figure 6 The second French storm. (a) The MSLP analysis at the verification time 00 UTC 28 December 1999. The other panels show t+60h forecasts started at 12 UTC 25 December (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) The T_L319L60 forecast (IE=23hPa, PE=904km), (c) the EPS control forecast (IE=23hPa, PE=595km), (d) the EPS ensemble-mean forecast, (e) EPS member 1 (the lowest RMSE, IE=4hPa, PE=138km), (f) EPS member 34 (the second lowest RMSE, IE=17hPa, PE=183km), (g) EPS member 31 (IE=2hPa (the lowest), PE=281km), (h) EPS member 21 (IE=6hPa (the second lowest) PE=292km), and (i) EPS member 14 (IE=11hPa, PE=454km). Twenty-eight EPS members had RMSEs smaller than the T_L319L60 forecast and 19 members had RMSEs smaller than the EPS control. The contour interval is 5hPa, with shading for values below 980hPa.

Table 4 summarises the number of EPS forecasts issued on 22 December (t+132h) and on 25 December (t+60h) with IEs and PEs within predefined intervals. Table 4 shows that the number of EPS members with IEs and PEs smaller than 10hPa and 300km, respectively, increases from zero to three between the t+132h and the t+60h forecast ranges and that the number of EPS members with IEs and PEs smaller than 20hPa and 600km increases from eight to twenty.

a) First French storm (verifying at 12UTC 26 December 1999)

21 Dec t+120h	DE 0-300km	DE 300-600km	DE 600-900km	DE > 900km
IE 0-10hPa	0 (3)	2 (2)	6 (2)	2 (7)
IE 10-20hPa	0 (1)	1 (1)	2 (1)	5 (6)
IE 20-30hPa	0 (0)	1 (1)	0 (2)	0 (1)
IE > 30hPa	0 (0)	0 (1)	19 (14)	0 (4)

b) First French storm (verifying at 12 UTC 26 December 1999)

24 Dec t+48h	DE 0-300km	DE 300-600km	DE 600-900km	DE > 900km
IE 0-10hPa	0 (1)	6 (6)	16 (5)	3 (2)
IE 10-20hPa	0 (1)	3 (5)	3 (1)	0 (2)
IE 20-30hPa	0 (0)	2 (6)	9 (8)	0 (5)
IE > 30hPa	0 (0)	0 (0)	2 (7)	1 (1)

Table 3 The first French storm. The number of EPS and HEPS (in brackets) perturbed members with intensity error (IE) and position error (DE) included in defined intervals, for ensembles started (a) on 21 December 1999 (t+120h) and (b) on 24 December 1999 (t+48h).

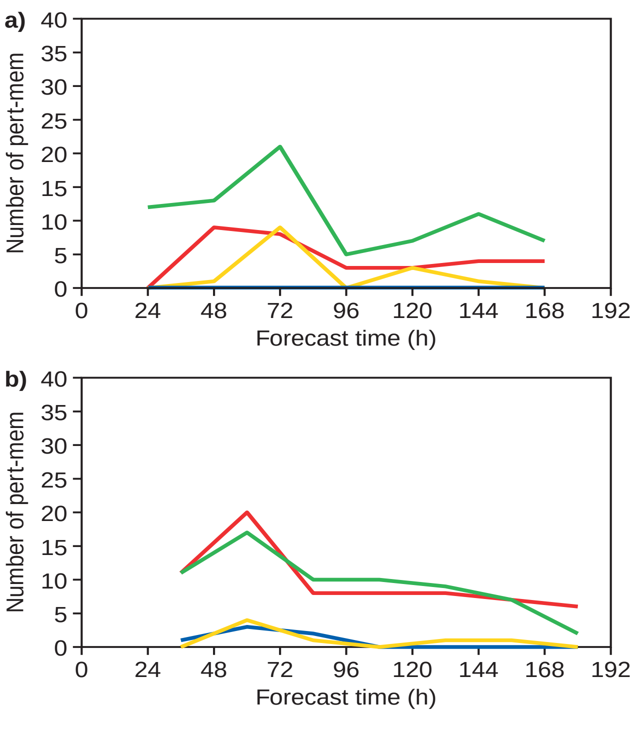

Figure 7 (a) As Figure 3, but for the first French storm verified at 12 UTC 26 December 1999. (b) As Figure 3, but for the second French storm verified at 00 UTC 28 December 1999.

The EPS forecast issued on 26 December (t+36h, not shown) was worse than the EPS issued the day before (25 December, t+60h, Figure 6) both in terms of RMSE (not shown) and IE and PE (Figure 7(b)). A possible reason for this poor 3h prediction is that the EPS initial perturbations are optimised to generate the proper spread among the ensemble members after two days of integration.

For verification time 12 UTC 26 December, Figure 8 (in a layout similar to Figure 1) shows the HEPS t+48h forecasts started on 24 December. Compared with the EPS (Figure 5), the HEPS members are better able to predict the small-scale vortex. HEPS member 49 has the lowest RMSE and the lowest IE and PE of all forecasts (5hPa and 90km compared with 13hPa and 405km for the operational T_L319L60 model, Table 1(b)).

Figure 7(a) shows the IEs and PEs for all the EPS and the HEPS forecasts started over the period 19 December (t+168h) to 25 December (t+24h). None of the EPS members had an IE and PEs smaller than 10hPa and 300hPa, while up to nine HEPS members had errors smaller than 10hPa and 300hPa. For all forecast ranges, HEPS forecasts are better able to predict storms with low IEs and PEs.

Considering the probabilistic prediction of the event "MSLP lower than 980hPa", the EPS and HEPS probability predictions differ only slightly and have similar BSs (not shown). The BSs of the HEPS are lower than (i.e. better than) or equal to the BSs of the EPS for five out of seven forecasts. Generally speaking, the quality of both the EPS and the HEPS probability forecasts for this event was lower than during the Danish storm, as rather few members showed low IEs and PEs. In fact, for the Danish storm more than 15 EPS and HEPS members had IEs smaller than 20hPa and PEs smaller than 600km for forecasts up to t+84h, with all members characterised by IEs and PEs lower than 20hPa and 600km at t+36h (Figure 3). In contrast, for the first French storm, for all forecast ranges, apart for 72h, fewer than nine EPS and thirteen HEPS members had IEs and PEs smaller than 20hPa and 600hPa (Figure 7(a)). (Note that care must be taken when comparing these BSs with the BSs obtained for the Danish storm since they have been computed over different areas.)

For verification time 00 UTC 28 December, Figure 9 shows the HEPS forecast started on 25 December (t+60h). For this forecast range, HEPS member 45 has the lowest RMSE and the lowest IE and PE of all forecasts (1hPa and 38km, compared with 23hPa and 904km for the operational T_L319L60 forecast, see Table 1(c), and 4hPa and 138km for the EPS member with the lowest errors).

Figures 7(b) shows the IEs and PEs for the EPS and HEPS forecasts started over the period 19 December (t+180h) to 25 December (t+36h). The HEPS has a slightly larger number of ensemble members with low IEs and PEs (Figure 7(b)), but it has fewer members with low RMSEs (not shown). Table 4 summarises the impact of resolution on the 132h and the 60h forecasts. At both these ranges, the HEPS has a larger number of forecasts with low IEs and PEs, but has also a larger number of members with large errors.

Considering the probabilistic prediction of the event "MSLP lower than 980hPa", the EPS and HEPS probability

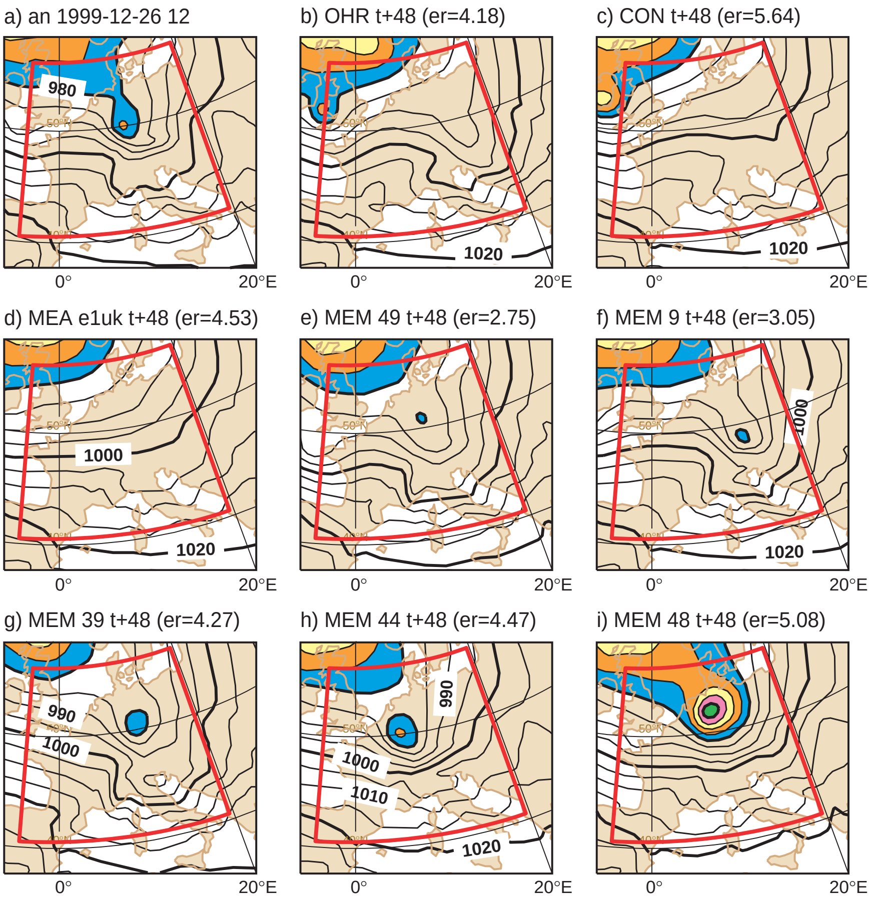

Figure 8 The first French storm. (a) The MSLP analysis at the verification time 12 UTC 26 December 1999. The other panels show t+48h forecasts started at 12 UTC 24 December (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) the TL319L60 forecast (IE=13hPa, PE=405km), (c) the high-resolution ensemble (HEPS) control forecast (IE=27hPa, PE=622km), (d) the HEPS ensemble-mean forecast, (e) HEPS member 49 (the lowest RMSE, IE=5hPa, PE=90km), (f) HEPS member 9 (the second lowest RMSE, IE=5hPa, PE=276km), (g) HEPS member 39 (IE=9hPa (the second lowest), PE=132km), (h) HEPS member 44 (IE=0.7hPa (the lowest), PE=200km), and (i) HEPS member 48 (IE=17hPa, PE=203km). Six HEPS members had RMSEs smaller than the T_L319L60 forecast) and 21 members had RMSEs smaller than the HEPS control. The contour interval is 5hPa, with shading for values below 980hPa.

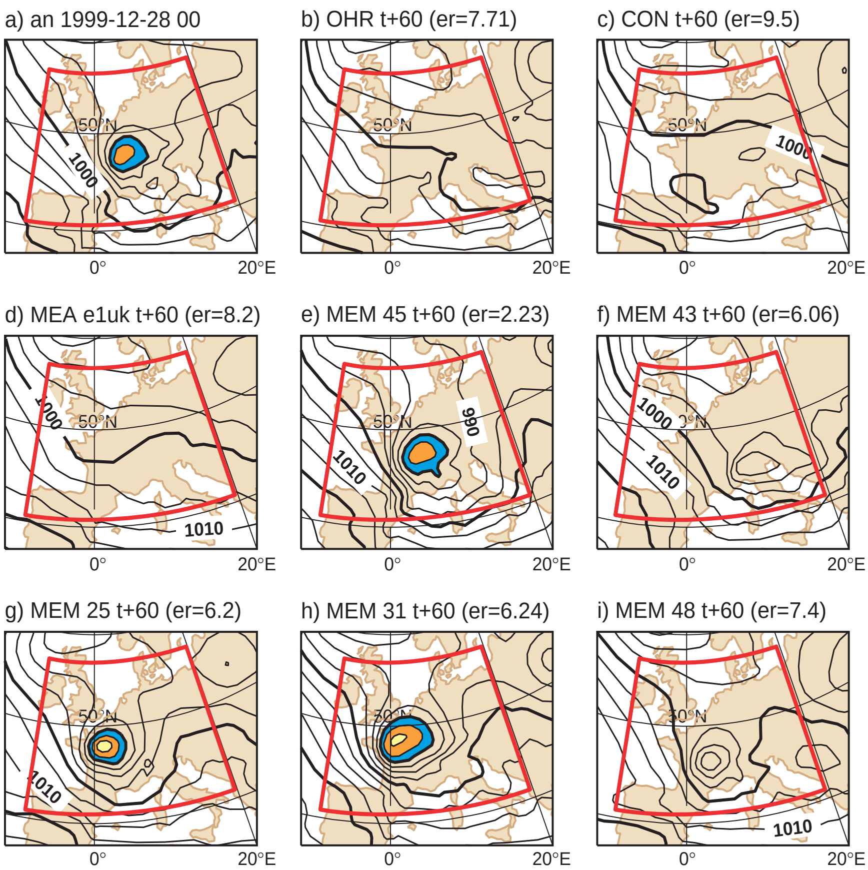

Figure 9 The second French storm. (a) The MSLP analysis at the verification time 00 UTC 28 December 1999. The other panels show t+60h forecasts started at 12 UTC 25 December (er is the root-mean-square error (hPa), IE is the intensity error (hPa) and PE is the position error (km)). (b) The T_L319L60 forecast (IE=23hPa, PE=904km) (c) the high-resolution ensemble (HEPS) control forecast (IE=30hPa, PE=481km), (d) the HEPS ensemble-mean forecast, (e) EPS member 45 (the lowest RMSE, IE=1hPa (the lowest), PE=38km), (f) EPS member 43 (the second lowest RMSE, IE=10hPa, PE=475km), (g) EPS member 25 (IE=4hPa, PE=222km), (h) EPS member 31 (IE=2hPa (the second lowest), PE=276km), and (i) EPS member 48 (IE=10hPa, PE=185km). Nine HEPS members had RMSEs smaller than the T_L319L60 forecast and 19 members had RMSEs smaller than the HEPS control. The contour interval is 5hPa, with shading for values below 980hPa.

a) Second French storm (verifying at 00 UTC 28 December 1999)

22 Dec t+132h	DE 0-300km	DE 300-600km	DE 600-900km	DE > 900km
IE 0-10hPa	0 (1)	0 (1)	3 (1)	4 (3)
IE 10-20hPa	4 (0)	4 (7)	7 (5)	5 (1)
IE 20-30hPa	0 (0)	1 (11)	8 (9)	2 (2)
IE > 30hPa	0 (0)	4 (2)	5 (3)	1 (3)

b) Second French storm (verifying at 00 UTC 28 December 1999)

25 Dec t+60h	DE 0-300km	DE 300-600km	DE 600-900km	DE > 900km
IE 0-10hPa	3 (4)	5 (4)	0 (0)	1 (1)
IE 10-20hPa	6 (1)	6 (4)	8 (1)	3 (3)
IE 20-30hPa	1 (1)	8 (8)	4 (7)	0 (3)
IE > 30hPa	0 (1)	0 (10)	5 (3)	1 (0)

Table 4 The second French storm. The number of EPS and HEPS (in brackets) perturbed members with intensity error (IE) and position error (DE) included in defined intervals, for ensembles started (a) on 22 December 1999 (t+132h) and (b) on 25 December 1999 (t+60h).

predictions are very similar and have similar BSs (not shown). The BSs of the HEPS are lower than or equal to the BSs of the EPS for five out of seven forecast times.

For verification time 00 UTC 28 December, the EPS horizontal resolution increase showed a neutral impact (not shown).

Summary

The performance of the ECMWF operational Ensemble Prediction System (EPS) during two periods of December 1999 characterised by intense storms over Europe has been analysed. At the time of the storms the EPS was based on 51 members with T_L159L40 resolution starting from the operational T_L319L60 analysis. The EPS performance has been compared with the performance of a high-resolution ensemble system (HEPS) based on 51 members with T_L255L40 resolution starting from a T_L511L60 analysis. Forecast verification has been focused on mean-sea-level pressure (MSLP). The quality of single deterministic forecasts has been assessed by computing the root-mean-square error (RMSE) inside a verification area centred on the cyclone position, and by computing the position and the intensity error in the prediction of the MSLP minimum value. The accuracy of probabilistic forecasts of the event "MSLP lower than 980hPa" have been assessed by computing the Brier score. Further details on the accuracy of probabilistic predictions are reported in *Buizza & Hollingsworth (2000).*

Generally speaking, results have shown that the EPS gave early indications of the possibility of a storm occurrence in the forecast range t+180h to t+144h for all three cases. EPS forecasts started on subsequent days confirmed and refined earlier ensemble forecasts in a very consistent way. The EPS proved to be particularly helpful in cases of large inconsistency between operational T_L319L60 forecasts issued on successive days. The EPS performed differently during the three cases. It was very successful in predicting the Danish storm, with EPS forecasts started on subsequent days consistently increasing the probability of occurrence, and with many EPS members correctly predicting the intensity and the position of the storm. The prediction was less accurate during the two French storms, with fewer EPS members correctly predicting the intensity and the position of the MSLP minimum value. Despite the poorer performance during the two French storms, the EPS provided forecasters with some indications of the chance of an intense storm. In contrast, the ECMWF operational deterministic T_L319L60 model did not give any useful indications, especially in the case of the second French storm.

Results indicate that the high-resolution ensemble HEPS is better able to predict correctly the intensity of severe storms, and thus to provide more skilful probabilistic products. This positive impact was very evident in the case of the Danish storm, both from the performance of the single ensemble members and from the quality of the probabilistic predictions of the event "MSLP lower than 980hPa". The impact was still positive but less evident in the case of the first French storm, and was detectable also in the quality of the probabilistic prediction of the event "MSLP smaller than 980hPa". The impact was less evident in the case of the second French storm. The comparison between the accuracies of the EPS and HEPS probabilistic predictions of wind-speed events confirmed the conclusions drawn from the detailed analysis of the MSLP predictions, in particular, the positive impact of the resolution increase (not shown).

One of the difficult aspects of ensemble predictions is how to summarise the forecast information contained in the ensemble without oversimplifying it. Results have indicated that the ensemble mean, which can be considered as the most immediate way to condense the ensemble of forecasts, may not be a useful forecast product in cases of extreme events. In contrast, MSLP stamp-maps showing all EPS members can provide the forecasters with indications of possible extreme weather events. Probability maps for the event "MSLP smaller than a defined threshold" have been shown to be a potentially very useful way to summarise the ensemble of MSLP forecast into a unique product. For the three cases under investigation, this threshold has been set to 980hPa. However the threshold value is case dependent, and forecasters should defined it "on the fly", depending on the atmospheric situation (the stamp-maps can guide the choice of this threshold).

In summary, these results suggest that ensemble prediction has entered a mature stage. The ECMWF Ensemble Prediction System can be used to issue early warnings of severe weather events. These results indicate that it is time to promote the use of ensemble products as input to risk assessment models.

The reader is referred to Buizza & Hollingsworth (2000) for a more detailed investigation of the performance of the EPS and the HEPS during the three storms. The positive impact on the ensemble performance of the resolution increase is supported by other comparisons between the EPS and the HEPS for a two-month winter period and for a one-month period. Work is in progress to document the results of these parallel integrations. ❑

Acknowledgments

Martin Leutbecher is thanked for providing the software used to identify local minimum values of mean-sea-level pressure.

References

Bell, **G.D.**, **Halpert**, **M.S.**, **Schnell**, **R.C.**, **Wayne Higgins**, **R.**, **Lawrimore**, **J.**, **Kousky**, **V.E.**, **Tinker**, **R.**, **Thiaw**, **W.**, **Chelliah**, **M.**, and **Artusa**, **A.**: 2000: Climate assessment for 1999. *Bull. Amer. Met. Soc.*, **81**, S1-S50.

Brier, **G.W.**, 1950: Verification of forecasts expressed in terms of probability. *Mon. Wea. Rev.*, **78**, 1-3.

Buizza, **R.B.**, **Petroliagis**, **T.**, **Palmer**, **T.N.**, **Barkmeijer**, **J.**, **Hamrud**, **M.**, **Hollingsworth**, **A.**, **Simmons**, **A.**, & **Wedi**, **N.**, 1998: Impact of model resolution and ensemble size on the performance of the ECMWF ensemble prediction system. *Q.J.R. Meteorol. Soc.*, **124**, 1935-1960.

Buizza, **R.B.**, & **Hollingsworth**, **A.**, 2000: Storm prediction over Europe using the ECMWF Ensemble Prediction System. *Meteorol. Appl.*, submitted.

Buizza, **R.B.**, **Miller**, **M.**, & **Palmer**, **T.N.**, 1999: Stochastic representation of model uncertainties in the ECMWF Ensemble Prediction System. *Q.J.R. Meteorol. Soc.*, **125**, 2887-2908.

Easterling, **D.R.**, **Evans**, **J.L.**, **Groisman**, **P.Ya.**, **Karl**, **T.R.**, **Kunkel**, **K.E.**, & **Ambenje**, **P.**, 1999: Observed variability and trends in severe weather climate events: a brief review. *Bull. Amer. Meteorol. Soc.*, **81**, 417-425.

Kunkel, **K.E.**, **Pielke Jr.**, **R.A.**, & **Changnon**, **S.A.**, 1999: Temporal fluctuations in weather and climate extremes that cause economic and human health impacts: A review. *Bull. Amer. Meteorol. Soc.*, **80**, 1077-1098.

Molteni, **F.**, **Buizza**, **R.**, **Palmer**, **T.N.**, & **Petroliagis**, **T.**, 1996: The ECMWF Ensemble Prediction System: methodology and validation. *Q.J.R. Meteorol. Soc.*, **122**, 73-119.

Roberto Buizza and Anthony Hollingsworth

The RMDCN Project in RA VI

In 1997, the Steering Group on the Regional Meteorological Data Communication Network (RMDCN) recommended a Managed Data Network to meet the RA VI and ECMWF data communication requirements. The Steering group further recommended to request ECMWF to lead and co-ordinate the procurement, implementation and operational monitoring of such a network for all RA VI Members. The ECMWF Invitation To Tender (ITT) for the RMDCN was issued in March 1998 and Equant was selected as the provider for the RMDCN.

The Network proposed by Equant was based on their Frame Relay and X25 services, using TCP/IP as the transport protocol. Frame Relay is a networking protocol that provides flexible bandwidth management with the following features:

- Committed information Rate (CIR), which defines the network bandwidth capacity that Equant commits to provide between RMDCN Members site.
- Excess Information Rate (EIR), which offers the ability to take advantage of unused network capacity at up to 1.5 times CIR. This facility is available on all CIRs up to 128 kb/s.

All the RMDCN Members were to be connected via an access line to the Equant in-country Frame Relay Point of Presence (POP). A fully managed Cisco Router and a back up of the access line were also included in the Equant service.

After the signature of the contract with Equant in December 1998, the first step was to know which WMO RA VI Members would take part in the Initial Deployment of the network. On 1 April 1999, the deadline to be included in the Initial Deployment, the membership of RMDCN comprised 31 countries: 17 ECMWF Member States (Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and Turkey), three ECMWF Co-operating States (Hungary, Iceland and Slovenia) and 11 countries from the Region VI (Bulgaria, Czech Republic, Former Yugoslav Republic of Macedonia, Jordan, Latvia, Lebanon, Lithuania, Poland, Romania, Slovakia and the Syrian Arab Republic).

Pilot Network

To validate the technical solution proposed by Equant and the performance of their Frame Relay service a pilot network was set up in April 1999. This pilot network was a prototype of the new network architecture provided by Equant and involved two meteorological services, the Instituto de Meteorologia (Lisbon) and Météo-France (Toulouse), and ECMWF.

During June and July 1999 ECMWF ran a set of tests to verify the planned configuration, the connectivity and the performance of the network. Initially, the tests showed routing problems and variability in the sustained network performance. These problems were resolved by a new router configuration provided by Equant in August 1999.

This period of installation and tests was very useful to identify logistical problems and to establish efficient communications and working methods (such as exchange of information with Equant, order procedures, technical details), as necessary at the start of any major project.

Initial Deployment

The process of arranging the connection of the remaining 29 National Meteorological Centres (NMCs) to the nearest Equant Point of Presence (POP) started in parallel. Getting all the technical details of the NMCs' connections to prepare the configuration of the routers took longer than anticipated. Logistical problems within Equant in the ordering process for the Leased Lines, the installation of cold standby routers and the supply of the ISDN backups led to new delays in the project. Problems in the configuration of the Frame Relay backbone and difficulties for ECMWF in communicating with some participants delayed the start of the Initial Deployment acceptance process.

In order to improve the communication with the participating countries, ECMWF set up a web site to provide information on the progress of the project. Configuration details, contact details, documents on the acceptance tests, and information on anything that may be of interest for the project were made available to the RMDCN community.

The implementation of the IP design of the network has also proved to be a very time consuming task. During the months of August and September the ECMWF project team worked closely with the Equant technical team to define and implement a suitable IP routing architecture for the RMDCN. At the beginning of October 1999, Equant implemented the final IP routing scheme and during the second week of October ECMWF and some RTHs checked the delivered network to make sure that the configuration of the routers was correct.

Acceptance of the Initial Deployment

Finally, on 18 October 1999, the User Site Acceptance of the Initial deployment started. Due to third party delays and regulatory authorities issues, Equant could not implement a connection for Poland and the Syrian Arabic Republic in time for the acceptance of the Initial Deployment. This left 29 countries plus ECMWF to accept their connection to the RMDCN.

The first step of the User Site Acceptance was to verify the correct delivery and installation of the equipment for each NMC. Then, all the participating NMCs were asked to complete the connectivity and performance tests developed by ECMWF for each protocol and each individual Permanent Virtual Circuit (PVC) they had with other NMCs. They also had to verify the functionality of their backup configuration.

Again, this phase was more difficult than expected. A large number of technical problems were discovered and resolved during this stage of the acceptance process. As a focal point for the RMDCN, the ECMWF project team dealt with the various problems encountered and provided via the RMDCN web site the status of the User Site Acceptance on a daily basis.

The second stage of the acceptance, the Reliability Acceptance test, started on 29 November 1999. All the participants in the Initial Deployment, except Poland and the Syrian Arab Republic, began a 30-day period of Reliability Acceptance. According to the acceptance criteria defined in the RMDCN contract, 90% of PVCs had to achieve 99.5% of service availability and the remaining PVCs had to achieve 98.5% of service availability, over a 30-day period. All the NMCs were asked to operate the links sufficiently to give assurance of good network service and good response times from the Equant Help Desk in the resolution of problems.

During the test period, NMCs and ECMWF sent test data or copies of the operational data over the network. ECMWF monitored the network and the Trouble Tickets opened by the participants. Most PVCs achieved the contracted Service Availability over the period without any problems. For a few countries the test had to be restarted.

By early February 2000 the last major hurdles to be overcome were the provision of the backup in some countries and the lack of documentation. By early March Equant had resolved all the problems preventing the acceptance of the Initial Deployment and on 15 March 2000, 15 months after the signature of the contract with Equant, the network was finally accepted.

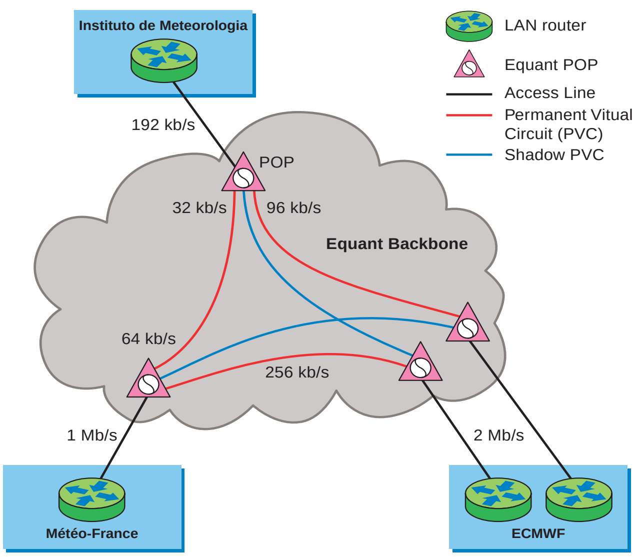

Figure 1 Pilot network

RMDCN configuration

In the meantime Estonia and Croatia had requested to join the RMDCN. Estonia was connected in December 1999 and passed its final acceptance on 4 July 2000. Croatia was connected to the network mid June 2000 and passed its final acceptance on 15 December 2000.

Also Poland is now connected; this happened in February 2000, just before the final acceptance of the Initial Deployment. The ECMWF configuration is given in Table 1.

Since 15 March 2000, 32 countries plus ECMWF are using the RMDCN for their operational communication and the majority of the old Leased Lines and GTS links have been cancelled. Today the RMDCN is a set of 306 PVCs achieving more than 99.5% of availability, an acceptable Service Level. So far, the RMDCN has performed reasonably well, the Frame Relay backbone is very stable and the delivered bandwidth is as expected. The EIR mechanism works very well and provides most PVCs more bandwidth than requested.

The regulatory issues which have until now prevented the connection of the Syrian Arab Republic have been resolved, as the local PTT in Syria has agreed to allow SITA, the partner of Equant in various countries, to provide the Meteorological Department with a connection to the RMDCN. Frame Relay is now available in Damascus, so instead of being connected to the RMDCN via X25, Syria will have a direct Frame Relay connection to the network.

The RMDCN is still evolving. Since the acceptance of the network, RMDCN members have requested various upgrades to their initial configuration. New asymmetric

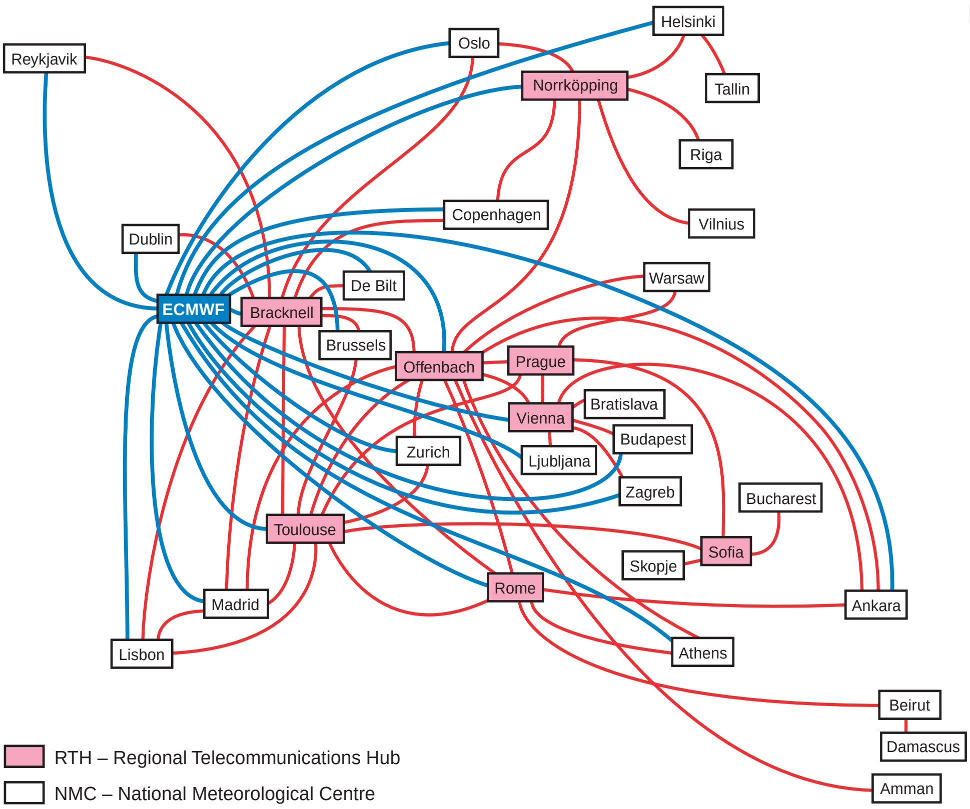

Figure 2 RMDCN configuration.

PVCs have been added, additional bandwidth has been requested by some NMCs and changes in the router configuration have been introduced. Of the remaining 17 RA VI Members, not connected to the RMDCN, four new countries, Bosnia & Herzegovina, Cyprus, Israel and Russia, have expressed the wish to join the RMDCN and are in the process of getting detailed pricing information from Equant. ECMWF is now in discussion with Eumetsat, the European organisation, about their connection to the Equant network.

The ECMWF project team is monitoring the RMDCN on a 24-hour basis and managing the Service level Agreement for the whole WMO region VI. All the changes and new requests affecting the network are also co-ordinated by the team. The manpower costs for these tasks are funded by the ECMWF Member States.

Conclusion

The deployment of the RMDCN in the WMO Region VI has been a good opportunity for some countries to get a significant upgrade of their GTS connection. NMCs have also taken the opportunity to migrate their GTS application from the X25 to TCP/IP protocol during the implementation of this managed network. TCP/IP is now the standard protocol for the RMDCN and only 6 PVCs are still configured to run x25 applications over TCP/IP.

The RMDCN has introduced new opportunities for the RA VI community by modernising the old GTS infrastructure. The RA VI data communication network is now more flexible; new connections or changes to the existing architecture can be easily introduced. In many cases the migration to the RMDCN has involved cost savings for the participants. ❑

	Remote Country	CIR in (kb/s)	CIR out (kb/s)
ECMWF – Reading	4 access lines @ 2048 kbps, each in a mission critical configuration		
	Austria	96	96
	Belgium	96	96
	Croatia	8	64
	Denmark	256	256
	Finland	96	96
	France	256	512
	Germany	512	512
	Greece	96	96
	Hungary	16	64
	Iceland	16	64
	Ireland	96	96
	Italy	96	96
	Netherlands	96	96
	Norway	96	96
	Portugal	96	96
	Slovenia	8	64
	Spain	96	96
	Sweden	96	192
	Switzerland	96	96
	Turkey	96	96

Table 1 ECMWF configuration

Matteo Dell'Acqua, Tony Bakker

ECMWF Educational Programme 2001

ECMWF has an extensive education and training programme to assist Member States and Co-operating States in the training of scientists in numerical weather forecasting, and in making use of the ECMWF computer facilities. All training courses consist of modules that can be attended separately. Since the course contents do not vary much from one year to another, a student may decide to attend the different modules in different years. Further information can be obtained from

http://www.ecmwf.int/services/training/index.html

The programme for 2001 is as follows:

Computer User Training Course

The three-week course in February-March on the use of ECMWF computer facilities consists of five modules of varying length. The objective of the course is to introduce users of ECMWF's computer systems to the Centre's facilities, and to explain how to use them. The course is divided into five separate modules, each consisting of some lectures and some practical sessions.

COM 1 (26 February – 2 March 2001):
Introduction for new users / MARS

- System and hardware overview
- Submitting batch jobs
- Access from Member States
- Data storage/retrieval facilities
- Running Fortran jobs
- Libraries
- MARS (Meteorological Archival and Retrieval System)
- Decoding/encoding routines
- Interpolation of data

COM 2 (5 – 7 March 2001):
Use of ECMWF supercomputing resources

- Fujitsu hardware review
- Fujitsu file system overview
- Measuring batch job performance
- I/O improvements
- Fortran vectorisation
- Debugging

COM 3 (8 – 9 March 2001):
SMS/XCdp

- SMS
- XCdp

COM 4 (12 – 13 March 2001):
MAGICS

- MAGICS subroutine library
- MAGICS programming

COM 5 (14 – 16 March 2001):
Metview

- Metview
- Metview macros

Students are assumed to have experience of a computer system elsewhere, to be familiar with ANSI 77 Fortran, to know basic UNIX commands, and to be able to use the *vi* editor.

For further enquiries and information contact:
compcourse@ecmwf.int or
http://www.ecmwf.int/services/training/index.html

Meteorological Training Course

The objective of the meteorological training course is to assist Member States in advanced training in the field of numerical weather forecasting. The course consists of five modules; four emphasise scientific training and one is aimed more at forecasters or people with forecasting experience.

MET OP (19 – 28 March 2001):
Use and interpretation of ECMWF products
(in case of oversubscription this course will be repeated on 4 – 13 June 2001)

- The ECMWF operational analysis and forecast system
- Verification and interpretation of numerical products
- Statistical and synoptic characteristics of ECMWF forecasts
- Methods of deterministic interpretation
- Use and value of the probabilistic Ensemble Prediction System
- Planned developments of the ECMWF operational system

Attendance at the other modules is not a requirement for participation in this module. Trainees not familiar with Metview may, however, want to take advantage the training module COM 5 (further details under Computer Training Course).

MET NM (2 - 11 April 2001):
Numerical methods, adiabatic formulation of models

- Atmospheric waves
- Numerical methods for weather prediction
- Governing equations/adiabatic formulation of large-scale models of the atmosphere
- Ocean wave modelling

MET PR (23 - 27 April 2001):
Predictability, diagnostics and seasonal forecasting

- Predictability
- Diagnostics
- Seasonal Forecasting

MET PA (30 April – 11 May 2001):
Parametrization of diabatic processes

- General aspects of parametrization and their relation to systematic forecast errors
- Parametrization of subgrid-scale orographic effects
- Radiation in numerical weather prediction
- Parametrization of moist processes
- Planetary boundary layer and land-surface processes

MET DA (14 – 23 May 2001):
Data assimilation and use of satellite data

- Observations
- Data assimilation concepts and algorithms
- Data assimilation techniques
- Satellite Data
- Control of gravity waves in data assimilation
- Diabatic data assimilation
- Data assimilation properties

Lectures notes for modules MET NM, MET PR, MET PA and MET DA are available from http://www.ecmwf.int/services/training/rcourse_notes/index.html.

For enquiries and information contact:
metcourse@ecmwf.int or
http://www.ecmwf.int/services/training/index.html

Seminar

A series of lectures dedicated to one specific theme is given at the beginning of September; the subject is different every year. In the year 2001 the topic is "Key issues in the parametrization of subgrid physical processes", and the seminar will take place during the week 3–7 September.

The parametrization of subgrid processes is a crucial aspect of numerical models of the atmosphere, not only because subgrid processes have a fundamental impact on the large-scale flow, but also because important forecast parameters like cloud cover, precipitation and near-surface variables, such as temperature and wind, are very much controlled by parametrization schemes. Only the highest-resolution meso-scale models partially resolve precipitating convection and gravity waves, but they still need parametrization schemes for radiation, turbulence, clouds, microphysics, and land-surface processes.

Parametrization has made substantial progress in recent years, and diagnostic work in large-scale models using atmospheric analyses and observations, improved observational techniques, field programmes and studies with fine-scale models have played a very important role in this development. However, parametrization of subgrid processes continues to be a major challenge for modelling at all resolutions.

The purpose of this seminar is to give a pedagogical overview of the current issues in parametrization. Lectures will also focus on problems at very high resolution, numerical aspects of the coupling of subgrid processes to each other and to the dynamics, problems with the diurnal cycle of weather parameters, and the important role of large-eddy models and cloud-resolving models in parametrization development. Tropical variability, the need for stochastic components in parametrization schemes, and the requirements of adjoint physics will also be emphasised.

Posters providing further information on the programme and application forms will be distributed around May 2001.

For enquiries and information contact:
seminars@ecmwf.int or
http://www.ecmwf.int/services/training/index.html

ECMWF publications

Technical Memoranda

290 **D.S. Richardson**: Measures of skill and value of ensemble prediction systems, their interrelationship and the effect of ensemble size. *October 2000*

308 **J.O.S. Alves**, **K. Haines** and **D.L.T. Anderson**: Sea-level assimilation experiments in the tropical Pacific. *July 2000*

309 **Č. Branković** and **D. Gregory**: Impact of horizontal resolution on seasonal integrations. *July 2000*

310 **A. Hollingsworth**, **E. Kooij-Connally**, **U. Modigliani**, **C. Edis-Williams** and **S. Moreby**: ECMWF Bibliography 1975 – 2000. *July 2000*

312 **J.W. Taylor** and **R. Buizza**: Using weather ensemble predictions in electricity demand forecasting. *Sept 2000*

314 **V. Marécal** and **J-F Mahfouf**: Four-dimensional variational assimilation of total column water vapour in rainy areas. *Sept 2000*

316 **L. Isaksen** and **A. Stoffelen**: ERS-scatterometer wind data impact on ECMWF's tropical cyclone forecasts. *November 2000*

317 **P.A. Chessa**,: Classifications and validation of the ECMWF EPS perturbed forecasts using pre-defined weather regimes. *Sept 2000*

318 **P.A.E.M. Janssen**, **J-R. Bidlot** and **B. Hansen**: Diagnosis of the ECMWF ocean-wave forecasting system. *Oct 2000*

ERA Reports

ERA40 PRS2 Onogi, K.:The long-term performance of the radiosonde observing system to be used in ERA-40.

EUMETSAT Reports

EUMETSAT/ECMWF Fellowship Programme Research Report No. 8: Assimilation of Meteosat radiance data within the 4D-Var system at ECMWF by Rose Munro, Graeme Kelly and Roger Saunders. *September 2000*

Workshop Proceedings

Seventh workshop on meteorological operational systems, 15-19 November 1999

Miscellaneous

ECMWF Brochure – The first twenty-five years . . . *September 2000*

ECMWF Calendar 2001

Feb 26 – 16 Mar	**Computer User Training Course**	
26 Feb – 2 Mar	**Com1 –**	Introduction for new users / MARS
5 – 7 Mar	**Com2 –**	*Use of ECMWF supercomputing resources*
8 – 9 Mar	**Com3 –**	*SMS/XCdp*
12 – 13 Mar	**Com4 –**	*MAGICS*
14 – 16 Mar	**Com5 –**	*Metview*
Mar 19 – 13 Jun	**Meteorological Training Course**	
19 – 28 Mar	**Met OP –**	*Use & interpretation of ECMWF products*
[4 – 13 Jun]		*[second session if required]*
2 – 11 Apr	**Met NM –**	*Numerical methods, adiabatic formulation of models*
23 – 27 Apr	**Met PR –**	*Predictability, diagnostics & seasonal forecasting*
30 Apr – 11 May	**Met PA –**	*Parametrization of diabatic processes*
14 – 23 May	**Met DA –**	*Data assimilation & use of satellite data*

Apr 2 – 3	**Security Representatives meeting**	
May 3 – 4	**Computer Representatives meeting**	
May 22 – 23	**Policy Advisory Committee**	*14th*
May 29 – 30	**Finance Committee**	*65th*
June 18 – 19	**Medium-Range Forecasts' Users Meeting**	
June 20 – 21	**Seasonal Forecasts' Users Meeting**	
June 28 – 29	**Council**	*54th*
July 2 – 5	**Workshop –** *Ocean Wave Forecasting*	
Sept 3 – 7	**Seminar –** *Key issues in the parametrization of subgrid-scale processes*	
Oct 1 – 3	**Scientific Advisory Committee**	*30th*
Oct 8 – 10	**Technical Advisory Committee**	*30th*
Oct 15 – 16	**Finance Committee**	*66th*
Oct 18 – 19	**Policy Advisory Committee**	*15th*
Nov 5 – 9	**Workshop –** *Reanalysis*	
Dec 10 – 11	**Council**	*55th*

Special Project allocations 2001–2003

Member State		Institution	Project title	2001 Fujitsu (units)	2001 Data storage (Gbytes)	2002 Fujitsu (units)	2003 Fujitsu (units)
Continuation Projects							
Austria	1	Universitat fur Bodenkultur, Vienna (Kromp-Kolb)	Vertical ozone transport in the Alps	500	5	500	500
	2	Univ. Innsbruck (Mayr)	Heavy convective precipitation over and along mountains - numerical simulations	1700	3		
	3	Univ.Vienna (Dorninger)	Estimating the energy budget climatology over the Alps from different data sources	5000	10		
	4	Univ.Vienna (Ehrendorfer)	Singular-vector-based multivariate normal sampling in ensemble prediction	7000	6	8000	9000
Belgium	5	Univ. Louvain (van Ypersele)	Modelling the climate and its evolution at the global and regional scales	20000	500	20000	20000
Finland/ Sweden	6	FMI (Fortelius)	BEEOS in BRIDGE (Better Exploitation of Existing Observations in BRIDGE)	20000	50	20000	20000
France	7	L.A.M.P. (Cautenet)	Chemistry, cloud and radiation interactions in a meteorological model	93	2	93	93
	8	CERFACS (Siefridt)	MERCATOR	100000	1000	100000	*under evaluation*
	9	CERFACS (Terray)	Decadal variability over the North Atlantic - European region	10000	150	10000	10000
	10	CERFACS (Thual)	Universal software for data assimilation: variational method for global ocean	10000	50	10000	10000
	11	CERFACS (Rogel)	Seasonal to interannual predictability of a coupled ocean-atmosphere model	10000	150	10000	10000
	12	Univ. Nice, CNRM, UNAM (Vernin, Bougeault, Masciadri)	Forecasting optical turbulence for Astronomy applications with the MesoNH mesoscale model coupled with ECMWF products	3000	30	3000	3000
	13	LSCE, CEA-CNRS (Claquin/ Balkanski/ Schulz)	Are the ECMWF weather predictions improved by accounting for mineral dust?	7000	40	11000	11000

Member State		Institution	Project title	2001 Fujitsu (units)	2001 Data storage (Gbytes)	2002 Fujitsu (units)	2003 Fujitsu (units)
Continuation Projects							
Germany	14	Univ. Koln (Speth)	Interpretation and calculation of energy budgets	100	6	100	100
	15	MPI, Hamburg (Bengtsson)	Numerical experimentation with a coupled ocean/atmosphere model	75000	375	90000	110000
	16	MPI, Hamburg (Bengtsson)	Simulation and validation of the hydrological cycle	80000	370	100000	130000
	17	MPI, Hamburg (Manzini)	Middle atmosphere modelling	60000	400	80000	110000
	18	GKSS, Geesthacht (Rockel)	Energy and water cycle components in regional forecasts, remote sensing and field experiments	10	0.2	10	10
	19	Univ. Munich (Stohl)	Validation of trajectory calculations	500	50	750	1000
	20	DLR, Wessling (Hoinka/ Egger)	Climatology of the global tropopause	3000	10	3000	3000
	21	D.L.R. (Doernbrack)	Influence of non-hydrostatic gravity waves on the stratospheric flow for field above Scandinavia	15000	80	20000	25000
Italy	22	ISDGM-CNR (Cavaleri)	Testing and application of a third generation wave model in the Mediterranean sea	3000	3	3000	3000
	23	ICTP, Trieste (Molteni)	Nonlinear aspects of the systematic error of the ECMWF coupled model	50000	60	50000	50000
	24	ARPA-SMR, Emilia Romagna & Italian Met Service (Paccagnella/Ferri)	Limited area model targeted ensemble prediction system (LAM-TEPS)	25000	24	25000	25000
Netherlands	25	KNMI (Siegmund)	Transport relevant for atmospheric chemistry	4000	10	4000	4000
	26	KNMI (van Velthoven)	Chemistry and transport studies with a 3D off-line tracer model	4000	30	4000	6000
	27	KNMI (Drijfhout)	Agulhas	20000	0	20000	20000
	28	KNMI (Komen)	Validation of reanalysed A/S fluxes	20000	5	20000	20000
	29	KNMI (Siebesma)	Large Eddy Simulation (LES) of boundary layer clouds	25000	30	25000	25000
	30	KNMI (Opsteegh / Hersbach)	Short term regional probabilistic forecasting	10000	12	10000	10000
	31	KNMI (Kelder)	Data assimilation of chemical species as observed by GOME and SCIAMACHY	1700	10	1700	1700
	32	KNMI (Burgers)	OGCM mixed-layer modules and assimilation	15000	100	15000	
	33	Netherlands Energy Research Foundation (ECN) (Slanina)	RECAB	2500	1	2500	2500
Norway	34	Univ. Bergen (Gronas / Kvamsto)	Cloud parametrization in general circulation models (GCMs)	100	5	100	100
	35	Univ. Oslo (Isaaksen)	Ozone as a climate gas	1500	5	1500	1500
	36	DNMI (Nordeng)	Targeted ensembles providing boundary values for limited area models	10000	12	10000	
Sweden	37	SMHI (Unden)	The HIRLAM 5 project	90000	500	120000	250000
Switzerland	38	Univ. Berne (Schupbach)	Classification of atmospheric circulation during extreme events in the Alps	5000	50	5000	5000
United Kingdom	39	Univ. Reading (Hoskins)	Routine back trajectories	3000	4	1500	1500
	40	Univ. Reading (Hoskins)	EPS and regime changes	12000	15		
	41	Univ. Cambridge (Lary)	Chemical data assimilation	3000	4	3000	3000
	42	Br. Antartic Survey, Cambridge (Turner / Cachlan-Cope)	Assessment of ECMWF forecasts over the high-latitude areas of the southern hemisphere	0	1		

Member State		Institution	Project title	2001 Fujitsu (units)	2001 Data storage (Gbytes)	2002 Fujitsu (units)	2003 Fujitsu (units)
New Projects							
Austria	1	Univ.Vienna (Hantel, Haimberger)	Atmospheric general circulation statistics from ERA-40 data	1000	20	2000	1000
Germany	2	MPI, Hamburg (Schultz)	Modelling studies with the global atmospheric chemistry model MOZART	29000	100	18000	
Sweden	3	SMHI (Langner)	Tracer transport/chemistry deposition modelling using meteorological data from ECMWF models	20000	50	30000	40000
United Kingdom	4	Univ. Reading (Hoskins)	Moist singular vectors	10000	15	10000	10000
Germany	5	Alfred Wegener Institute (Rinke)	Sensitivity runs with HIRHAM	2000	100	2000	2000
Total requested				**792503**	**4445.2**	**869253**	**953503**

Member State computer resource allocations 2001

Member State	Fujitsu (kunits) Basic allocation	Fujitsu (kunits) Boundary condition project	Fujitsu (kunits) Net allocation	Data (Gbytes)
Belgium	436	167	269	2275
Denmark	363	139	224	1892
Germany	2075	0	2075	10827
Spain	683	262	421	3561
France	1433	0	1433	7477
Greece	321	123	198	1672
Ireland	273	105	168	1422
Italy	1145	440	705	5972
Yugoslavia *	272	104	168	1419
Netherlands	544	208	336	2840
Norway	343	131	212	1790
Austria	401	154	247	2094
Portugal	306	117	189	1598
Switzerland	464	178	286	2419
Finland	319	122	197	1663
Sweden	410	157	253	2141
Turkey	369	141	228	1924
United Kingdom	1202	0	1202	6269
Special projects	1041	0	1041	5745
Total	12400	2548	9852	65000

* In accordance with UN Security Council Resolution 757 (1992) of 30 May 1992, the Council instructed the Director to suspend the telecommunications connection to Belgrade with immediate effect. This took place on 5 June 1992. As a consequence no operational products are disseminated to Belgrade and access to the Centre's computer system is not available to Belgrade.